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KENTUCKY RIVER BASIN REPORT ON THE BENEFITS TO POLLUTION ABATEMENT AND WATER SUPPLY RESULTING FROM LOW-FLOW AUGMENTATION

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

July 1957

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KENTUCKY RIVER BASIN

Report on the Benefits to Pollution Abatement and Water Supply Resulting from Low-Flow Augmentation

Prepared By

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Prepared at the request of and in cooperation with the District Engineer, Louisville District, Corps of Engineers

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34

TABLE OF CONTENTS

	Page
INTRODUCTION	1
CONCLUSIONS	2
POLLUTION ABATEMENT	4
Principles of Pollution-Abatement Evaluation	4
Present Conditions	6
Municipal Sewage Discharges	6
Industrial Waste Discharges	6
Stream Quality	7
Benefits of Increased Flow	14
WATER SUPPLY	18
Municipal	18
Industrial	21
Benefits of Increased Flow	21

INTRODUCTION

In accordance with a request dated July 26, 1956, from the office of the District Engineer, Louisville District, Corps of Engineers, U. S. Army, the Public Health Service has conducted a study of the water supply and waste disposal problems of the Kentucky River Basin.

This report evaluates the pollution abatement and public-water-supply benefits resulting from projected low-flow augmentation in the Kentucky River and its major tributaries.

Conclusions have been drawn from an analysis of data collected during the Ohio River Pollution Survey (1939-1940), from information supplied by the Kentucky Water Pollution Control Commission, from reports and publications of other agencies, and from data collected during a brief reconnaissance of the region. A complete list of the reports and publications used appears at the end of this report.

CONCLUSIONS

1. In general, the waters of the Kentucky River Basin show little evidence of pollution.

2. There are a few localized pollution problems due to the discharge of municipal and industrial wastes.

3. The Kentucky Water Pollution Control Commission has established treatment requirements for the known sources of pollution.

4. The largest single benefit attributable to reservoir operation should be based upon the development of an adequate industrial water supply. This value, while potential only at this time, should be very large.

5. An increased minimum flow in the North Fork Kentucky River would be beneficial to the town of Hazard. An annual benefit of $7,050 has been calculated from the difference in cost between secondary and primary sewage treatment. A continuous minimum flow of 8.2 cfs at Hazard, an increase of 6.2 cfs over the present one-month-in-ten-years drought flow, would be equivalent to secondary treatment.

6. Augmented flow in Goose Creek would likewise benefit Manchester annually by $2,240 if a continuous minimum flow of 2 cfs at Manchester were achieved. An additional benefit, $1,700 annually, not directly attributable to Manchester, would accrue from an improvement in water quality which would exceed that obtained with the degree of sewage treatment recommended by Kentucky.

7. A continuous minimum flow of 400 cfs in the Kentucky River at Frankfort would benefit industry in that area. Specifically this flow

would permit an existing industry to operate at any time of the year, instead of only during high flows on the Kentucky River. Benefits are estimated to be $7,900. The flow augmentation required would be 150 cfs added to the present one-month-in-ten-years drought flow of 250 cfs.

8. There are tangible benefits attributable to increased quantity of water available for municipal use. A minimum continuous flow of 10 cfs in the North Fork of Kentucky River near Hazard would provide a benefit of $46,000 annually. A minimum continuous flow of 100 cfs in the Kentucky River near Winchester would provide a benefit of $175,000 annually immediately as an assured water supply to Lexington, Ky. and an additional $50,000 annually at such time as Richmond and Winchester, Ky. utilize the Kentucky River as a source of raw water.

POLLUTION ABATEMENT

Principles of Pollution Abatement Evaluation

In general, where wastes are discharged into flowing streams, the seriousness and the extent of the damage caused by the resulting pollution depend upon the volume of stream flow as related to the amounts and strengths of the wastes discharged. Various other factors are also involved, so that it is not practicable to establish standard dilution ratios which could be applied generally. Nevertheless, the dilution available is one of the most important factors governing the extent and seriousness of pollution effects.

Pollution damage can be decreased either by reducing the waste load or by increasing the volume of dilution water. As most streams have widely varying natural flows, and as the design of waste-treatment works must be based upon critical low-flow conditions, it is frequently possible to reduce the required treatment by storing flood waters for release during low-flow periods.

Several important qualifications to these statements must be made. For many types of wastes, dilution alone can not be considered an entirely satisfactory substitute for treatment, at least within the range of dilutions which it might be practicable to provide. For example, oils and floating solids will be objectionable in many cases regardless of how much dilution water is available. Settleable solids, either putrescible or inert (e.g., coal washer wastes), will not be greatly affected by increased dilution. Sludge deposits from sewage or other organic wastes

may affect the stream out of all proportion to the pollution load in solution and in suspension. Neither does dilution solve problems of bacterial pollution. In these cases, the effects of dilution may be offset by the shorter travel time between the source of pollution and the point of water use since fewer organisms die in the reduced interval. In solving such pollution problems waste treatment is essential; although additional dilution may be a valuable supplement to treatment, it can not be considered a satisfactory substitute.

Primary treatment of municipal wastes is considered necessary before any benefits can be credited to dilution flows as equivalent treatment plant costs. Where minimum natural flow is sufficient to dilute effluents of primary sewage treatment plants, maintaining a satisfactory minimum dissolved oxygen content downstream from the treatment plant outfall, no benefits can be credited to additional dilution water. Conversely, where natural flows are not sufficient to maintain a satisfactory dissolved oxygen content, supplementary dilution flows will have a monetary value. Flow regulation in such cases will effect savings in waste treatment costs insofar as it substitutes dilution for physical treatment in excess of the essential minimum.

If acid mine drainage is the polluting material, low-flow augmentation decreases acid concentrations at times of normally low-flows; benefits are estimated from the reduced expenses of using acid water. In the event there are no users, no tangible benefits can be assigned to the reduced effect of acid mine drainage in the stream concerned.

Present Conditions

Municipal Sewage Discharges

The 1950 census showed a population of 520,000* in the Kentucky River Basin, 135,000 of these people, or 26 per cent, can be regarded as urban. Table I shows the municipalities or institutions in the basin with satisfactory waste treatment according to the Kentucky Water Pollution Control Commission. Table II shows those communities with unsatisfactory waste-treatment facilities and the degree of treatment recommended by the Kentucky Water Pollution Control Commission.

Industrial Waste Discharges

There are numerous coal washeries in the Eastern Coal Field Region. A few of these use satisfactory treatment to remove coal fines, but the others do not. Table III presents a list of the coal washeries discharging into streams of the Kentucky River Basin with indications as to whether or not the discharge of coal fines is satisfactory.

There are distilleries and other plants located in the Lexington-Frankfort area and along the lower reaches of the Kentucky River. The distilleries are responsible for most of the organic industrial waste discharged in the basin. At the present time almost all of the plants have installed adequate treatment and disposal facilities; several plants are no longer operating, and one small plant operates only during seasons of relatively high stream discharge.

* A report by the Kentucky Agricultural and Industrial Development Board estimates the 1955 population of the basin as 509,500, a decrease of about two per cent from the 1950 population. This net decrease results from the widespread emigration in the Eastern Coalfield Region which offsets a population increase in the counties of the Bluegrass Region.

Table I

Municipalities or Institutions in the Kentucky River Basin Having Satisfactory Sewage Treatment

Municipality or Institution	Population (1950 Census)	Receiving Stream	Type of Treatment
Berea	3,372	Brush Fork of Silver Creek	Complete
Danville	8,686	Clarks Run of Dix River	Complete
Frankfort	11,916	Kentucky River	Primary and Chlorination*
Georgetown	5,516	North Fork of Elkhorn Creek	Complete
Greendale, House of Reform	-	To Sinkhole	Complete
Kentucky State Hospital	-	Herrington Lake	Complete
Lancaster	2,402	Dix River	Complete
Midway	950	Lee's Br. to South Fork of Elkhorn Cr.	Complete
Nicholasville	3,406	Town Br. of Jessamine Creek	Complete
Owenton	1,249	Eagle Creek	Secondary Expansion*
Richmond	10,268	Dreaming Creek to Otter Creek	Complete
Stanford	1,861	St. Asaph Creek to Dix River	Complete
USPHS Narcotics Farm	4,000	Town Branch	Complete
Versailles	2,760	Glenns Creek	Complete
Whitesburg	1,393	North Fork of Kentucky River	Complete*
Wilmore	2,337	Jessamine Creek	Complete

* Under Construction

Table II

Communities in the Kentucky River Basin
Having Unsatisfactory Sewage Treatment

Community	Population (1950 Census)	Receiving Stream	Treatment Required
Beattyville	1,042	Kentucky River	Complete
Hazard	6,986	North Fork of Kentucky River	Complete
Irvine-Ravenna	4,238	Kentucky River	Primary and Chlorination
Jackson	1,978	North Fork of Kentucky River	Primary and Chlorination
Lexington	55,534	Town Br. to South Fork of Elkhorn Cr.	Expansion of Entire Plant
Manchester	1,706	Goose Cr. to South Fork of Kentucky R.	Complete
Mecn, Fleming and McRoberts Area	2,898	North Fork of Kentucky River	Complete

Table III

Coal Washeries Discharging to Streams
in the Kentucky River Basin

Category	Type Treatment
5 Coal Washeries	Satisfactory
11 Coal Washeries	Unsatisfactory

Table IV

Industries Discharging Wastes to Streams
in the Kentucky River Basin

Category	Type Treatment
12 Distilleries	Satisfactory(1)
2 Glass Works	Satisfactory
1 Packing Company	None (Very little waste)
1 Creamery	Complete
1 Button Company	Complete
2 Food Processors	None (Very little waste)

(1) Certain distilleries operate during high flows in receiving streams, have cattle feed recovery processes and evaporation, or have complete treatment.

Table IV is a summary of the distilleries and industries other than coal washeries discharging to streams in the basin, with notes on their treatment facilities.

Stream Quality

The chemical and bacteriological tests which can be used to evaluate the sanitary quality of a stream are many and varied. In this study the available data and those obtained during the field survey included tests for dissolved oxygen (D.O.), biochemical oxygen demand (B.O.D.), pH, temperature, coliform organisms, and acidity or alkalinity. The significance of each of these measurements in determining the sanitary quality of water is discussed here.

Temperature - The temperature of water controls the oxygen solubility and thus the saturation level of dissolved oxygen in the stream. The rate of natural purification and bacterial growth is increased or diminished with higher or lower temperatures, respectively.

pH - pH is defined as the negative logarithm to the base 10 of the hydrogen ion concentration. The pH value indicates the relative acidity or alkalinity of a water, with the neutral point at pH 7.0. Values lower than 7.0 indicate the presence of acid salts and, from pH 7.0 to 14.0, the presence of alkalies or alkaline earth salts is indicated.

Dissolved Oxygen (D.O.) - Normally the amount of oxygen dissolved in water of a stream is limited by the saturation value (9.17 p.p.m. at 20°C) which is a function of water temperature, but in some cases, as result of the photosynthetic action of some living green organisms, this value may be exceeded, causing "supersaturation." The saturation value decreases with higher temperatures. To support fish and aquatic life

and for natural aerobic purification of stream waters, dissolved oxygen must be present. The minimum quantity permissible is dependent on the quality of the water desired. Dissolved oxgyen must be present to prevent nuisance conditions associated with putrefactive decomposition of waste materials in a stream. Dissolved oxygen values below the saturation level are almost always an indication of the presence of organic material which is being biologically oxidized and thus utilizing oxygen from the stream water.

Biochemical Oxygen Demand (B.O.D.) - The biochemical oxygen demand (frequently referred to as B.O.D.) of sewage, sewage effluents, polluted waters, or industrial wastes is the oxygen (in parts per million) required during stabilization of the decomposable organic matter by aerobic bacterial action. Complete stabilization requires more than 100 days at 20°C, but such long periods of incubation are impracticable in any but research investigations. Consequently a much shorter period of incubation is used. Incubation for 5 days at 20°C is recommended as the standard procedure and this recommendation was followed during the field study. Conversion of the data from one incubation period to another, or from one temperature to another, may be approximated.

As the amount of dissolved oxygen which can be present in oxygen saturated water decreases with rising temperatures, and as the rate of biochemical oxidation increases as the temperature rises, critical stream conditions usually result during warm months, particularly since these high temperatures are often associated with low stream flows.

* All B.O.D. data included in this report are based on 5-Day, 20°C. B.O.D. unless otherwise noted.

Coliform Group Organisms - This determination is a sensitive indicator of sewage pollution, since it shows the approximate density of organisms that are normally found only in very small numbers in unpolluted streams. Coliform bacteria are normally present in the intestines of warm-blooded animals and are discharged in vast numbers in human feces, which constitute the main source of these bacteria in sewage. The coliform density is usually measured as "most probable number" (M.P.N.) of organisms per 100 milliliters of sample. This method of reporting the results of examinations is commonly known as the "M.P.N."

Alkalinity and Acidity - The alkalinity of water, which may be defined as its capacity for neutralizing acid, is usually due to the presence of biocarbonate and carbonate ions. In some waters hydroxide, borate, silicate, or phosphate ions may also contribute to it. Alkalinity is determined by titration with sulfuric acid to an end point of pH = 4.0. In this study all titrations of alkalinity and acidity were performed electrometrically.

The acidity of water, may be defined as the capacity for neutralizing base. Acidity is normally associated with the presence of carbon dioxide, mineral and organic acids, and salts of strong acids and weak bases. Mineral acidity is determined by titration with base to an end point of pH = 4.5, and total acidity by titration to an end point of pH = 8.3. Acidity and alkalinity are reported as ppm $CaCO_3$.

A detailed discussion of the stream sanitation problems of the Kentucky River Basin was previously presented in the Ohio River Pollution Survey Report (Vol. III, pp. 669-687). The river system was surveyed at times of low-flow during 1939-1940. Since that time pollution from

municipal and industrial wastes has been reduced significantly. Those communities listed in Table II, however, create much the same conditions as they did in 1939-1940. Data taken downstream from places where no treatment has since been instituted probably still represent the B.O.D., D.O., and coliform organism concentrations to be expected during low-flow periods.

These data have been supplemented by current information supplied by the Kentucky Water Pollution Control Commission and by measurements taken during a brief reconnaissance of the Basin by Public Health Service personnel. During the spring of 1957, determinations of D.O., acidity or alkalinity, and pH were run on samples taken from numerous streams in the Basin. The sampling points were distributed so as to provide a thorough coverage of the major streams and spot checks of those smaller streams suspected of carrying a particular waste. While the actual values obtained do not represent extreme flow conditions, the variations in samples from different locations show the differences in water quality among the points sampled. The data of the 1939-1940 survey are presented in Table V, and those of the 1957 reconnaissance in Table VI. From these two sets of data and the additional information furnished by the Kentucky Water Pollution Control Commission, estimates of water qualities throughout the river system can be made.

The three main headwater streams of the Kentucky River, and their tributaries are all swiftly flowing streams capable of rapid self-purification in relatively short reaches. As a result of this stream characteristic and the limited industrial and municipal development, the waste discharges in the upper part of the basin create a series of local pollution problems but do not damage long reaches of the streams.

Table V

Summary of Individual Results of Sampling
in the Kentucky River System in 1939

Sampling Point	October, 1939 B.O.D. (ppm)	Dissolved Oxygen (ppm)	Dissolved Oxygen (% Sat.)	pH	Coliforms (MPN/ml)
Boone Fork, below Neon	3.3	6.3	59	7.9	200
N. Fk. Ky. R., above Whitesburg	1.0	9.2	81	7.8	97
N. Fk. Ky. R., above Hazard	2.6	9.1	96	7.6	110
N. Fk. Ky. R., below Hazard	106	0.0	00.0	7.4	110,000
N. Fk. Ky. R., at Chavies	1.7	10.3	107	7.5	5
N. Fk. Ky. R., above Jackson	0.7	9.0	84	7.4	110
N. Fk. Ky. R., below Jackson	3.3	7.6	70	7.6	7
Middle Fk. Ky. R., below Hyden	0.9	8.9	82	7.2	16
Goose Creek, above Manchester	2.0	6.0	57	7.2	60
Goose Creek, below Manchester	3.8	4.7	41	7.3	54
Kentucky River, above Beattyville	1.8	7.0	79	7.3	120
Kentucky River, below Beattyville	1.6	7.0	79	7.3	23
Kentucky River, above Ravenna	3.1	5.2	58	7.1	95
Kentucky River, below Irvine	2.6	5.2	56	7.2	430

Table V (Con't.)

Summary of Individual Results of Sampling
in the Kentucky River System in 1939

Sampling Point	October, 1939 B.O.D. (ppm)	Dissolved Oxygen (ppm)	Dissolved Oxygen (% Sat.)	pH	Coliforms (MPN/ml)
Kentucky River, at Clay Ferry	0.9	6.5	72	7.4	32
Kentucky River, at Camp Nelson	1.0	8.5	94	7.7	1
Ky. R., Lock #4 at Frankfort	1.8	5.9	68	7.7	350
Ky. R., 4 Miles below Frankfort	2.3	3.8	43	7.4	170
S. Fk. Elkhorn Ck., at Forks of Elkhorn	2.5	9.7	105	8.3	12
*Kentucky River, at Gratz	1.3	11.4	102	7.7	29
*Kentucky River, at Mouth	1.6	11.0	99	7.6	34

* April, 1939

Table VI

Data of Field Reconnaissance in April 1957

Sampling Point	Date	Time	Estimated Discharge cfs	Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	pH	Alkalinity Phen.	Alkalinity Total
Kentucky River									
Mouth	4-25	1:15P	-	19	9.1	97.3	8.0	0	70
Lock No. 2	4-16	4:30P	16,500	11.5	11.2	102	7.8	0	74
Lock No. 3	4-16	3:00P	-	11	11.1	100	7.6	0	74
Lock No. 4	4-16	12:30P	7,940	11	11.1	100	8.0	0	78
Below Frankfort (Ky 1211)	4-16	1:00P	7,900	11	11.2	101	7.9	0	65
Above Frankfort (US 60)	4-16	11:00A	7,900	11	11.1	100	7.5	0	59
Lock No. 5	4-19	9:30A	7,000	15	10.6	104	7.9	0	70
US 68	4-19	11:30A	7,000	13	10.5	99.1	7.9	0	64
KY 39	4-19	2:30P	-	15	10.6	104	7.7	0	46
US 25	4-19	4:30P	-	16	10.6	107	7.5	0	42
Irvine	4-20	10:30A	-	16	10.9	110	7.4	0	28
Beattyville	4-20	12:30A	-	18	9.0	94.3	7.0	0	20
North Fork Kentucky River									
Jackson	4-21	3:30P	-	21	8.8	97.8	7.3	0	26
Chavies	4-22	1:00P	40	21	8.4	93.3	7.3	0	31
Darfork (Ky 15)	4-22	11:00A	-	21	8.2	91.1	7.5	0	42
Below Hazard (Ky 15)	4-22	10:15A	-	21	8.45	93.9	7.6	0	40
Above Hazard	4-22	8:30A	20	21	8.55	95.0	7.5	0	40
Above Hazard (Junction 15-7)	4-22	3:00P	-	22	8.8	100	7.7	0	42
Cornettsville	4-22	4:30P	-	21	9.2	102	7.9	0	57
Below Whitesburg (Ky 588)	4-23	1:00P	30	20	9.9	108	8.1	0	130
Above Whitesburg	4-23	12:30P	-	18	8.8	92.2	7.9	0	102
Mayking (Ky 805)	4-23	11:30P	20	17	8.5	87.3	7.7	0	116

Table VI (Con't.)

Data of Field Reconnaissance in April 1957

Sampling Point	Date	Time	Estimated Discharge cfs	Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	pH	Alkalinity Phen.	Alkalinity Total
Middle Fork									
Mouth (Ky 52)	4-20	1:15P	60	19	9.3	98.9	7.1	0	22
Ky 30	4-24	12:15P	100	22	8.3	94.0	7.5	0	24
Buckhorn	4-22	2:00P	80	21	8.8	97.8	7.4	0	23
Hyden	4-23	3:00P	20	21	8.6	95.6	7.5	0	20
South Fork Kentucky River									
Mouth	4-20	12:00N	500	19	9.7	104	7.1	0	20
Booneville (Ky 28)	4-24	11:15A	250	22	8.05	91.2	7.2	0	26
Oneida	4-24	10:00A	75	22	8.55	96.8	7.4	0	18
Tributaries:									
of Kentucky River									
Eagle Creek									
Mouth (US 227)	4-25	11:30A	300	22	7.05	79.8	8.3	0	216
Sanders (Ky 36)	4-17	10:00A	75	12	10.25	94.6	8.1	0	208
Delia (Ky 36)	4-17	12:00N	60	12	10.5	97.0	8.1	0	230
Eagle Springs (US 25)	4-17	2:00P	25	12	11.5	106	8.1	0	240
Elkhorn Creek									
Mouth (Ky 35)	4-17	9:00A	150	12	11.0	102	8.2	0	140
Peaks Mill Rd.	4-18	11:30A	100	14	11.2	108	8.4	0	148
S. Fk at Confluence	4-18	12:30P	30	14	11.15	108	8.6	0	140
S. Fk below Town Br.	4-18	2:45P	10	15	9.35	92.1	7.9	0	146
Town Br. at Yarnalltown	4-18	3:30P	10	16	7.25	72.9	7.8	0	168
N. Fk at Confluence	4-18	1:00P	40	15	12.05	119	8.6	0	150
N. Fk at Great Crossing	4-18	2:00P	10	13	10.3	97.2	8.2	0	148

Table VI (Con't.)

Data of Field Reconnaissance in April 1957

Sampling Point	Date	Time	Estimated Discharge cfs	Temp. °C.	Dissolved Oxygen ppm	Dissolved Oxygen % Sat.	pH	Alkalinity Phen.	Alkalinity Total
Benson Creek at Mouth	4-16	1:30P	10	12	9.5	87.7	8.2	0	203
Glenns Creek at Mouth	4-18	10:15A	10	17	10.6	109	8.5	0	152
Dix River below Dam	4-19	12:00N	No Discharge						
Lake Herrington (Ky 152)	4-19	12:15P	-	16	8.3	83.4	7.8	0	72
Red River (Ky 89)	4-20	9:00A	40	18	9.2	96.4	7.6	0	61
Clay City	4-21	10:30A	30	19	8.7	93.0	7.4	0	49
State Pk.	4-21	3:00P	5	20	9.7	105	7.6	0	32
of North Fk. Kentucky River									
Lotts Ck. at Mouth (Ky 80)	4-22	11:15A	7.	20	-	-	3.9	0 (8)	0 (58)
Carrs Fk. at Mouth	4-22	3:15P	15	23	-	-	4.9	0 (0)	6 (10)
Mason's Ck. at Mouth	4-22	3:45P	7	22	-	-	7.3	0	20
Leatherwood Ck. at Mouth	4-22	4:00P	30	22	8.5	96.3	7.7	0	38
Potter's Fk. at Mouth	4-23	9:15P	15	16	9.3	93.5	7.9	0	188
Yont's Fk. at Mouth	4-23	8:30A	7	16	10.0	101	8.0	0	160
Rt. Fk. Big Ck. at Mouth	4-23	1:30P	10	22	-	-	3.4	0 (30)	0 (96)
of South Fk. Kentucky R.									
Red Bird River (US 421)	4-23	3:45P	100	22	8.85	100	7.4	0	22
Goose Creek									
Above Manchester	4-24	8:00A	20	21	8.15	90.7	7.1	0	22
Below Manchester	4-24	8:30A	20	20	8.15	88.6	7.1	0	24

The data in Table V show that the stream quality in the headwater streams is impaired by organic pollution in reaches below Neon, Fleming, and McRoberts, below Hazard, below Jackson, and below Manchester. At low flows oxygen is totally depleted in the North Fork below Hazard and B.O.D. concentrations of about 100 ppm exist. At Chavies, 22 miles below Hazard, the stream has completely recovered from this pollution. Below the other communities B.O.D. concentrations of less than 5 ppm were found at low flows, and at only one place the oxygen was depleted to less than 50 per cent of saturation. On Goose Creek below Manchester, a D.O. of 41 per cent of saturation (4.7 ppm) was found; this, however, represents a decrease of only 1.3 ppm from the D.O. level above Manchester.

The coliform organism measurements of 1939 show that the most serious pollution is below Hazard, but significant MPN values occur in many of the headwater streams due to sewage from isolated dwellings and small communities.

In 1957, when samples were taken at a period of moderately high flow, a uniformly high water quality was found throughout the basin. Dissolved oxygen concentrations were usually near saturation with a few slightly lower values below some sources of pollution. The pH values were rather high in most cases, approaching 8.0 in streams not carrying acid loads and in the main rivers. Alkalinities of about 100 ppm were found in many of the larger tributaries and in the lower reaches of the main stream.

Several smaller tributaries contain acid mine drainage, but the large streams are not seriously affected. In 1939, Thornton Creek,

Irishman Creek, and Yellow Creek were found to have low pH values, which are indicative of this waste. In 1957, Carr's Fork, Big Creek and Lott's Creek carried large acid loads. Local residents indicated that other streams occasionally contained some acid. None of these streams influence pH significantly in the three main forks or the main stream itself; the high alkalinity of the natural runoff is probably responsible.

In 1957, the North Fork of the Kentucky River was heavily polluted with coal fines between the confluence of Leatherwood Creek and Hazard. The water itself was carrying noticeable quantities of suspended coal dust and the stream bed was covered with settled coal. The major load apparently enters from Leatherwood Creek, to which three coal washeries discharge. Some fines apparently enter from Carr's Fork and probably some from other streams in the area. The water-treatment plant on Goose Creek at Manchester has been seriously affected in the past by the coal fines discharged at coal washeries upstream from the town.

Coal fines from washery operations tend to settle out on the stream bed during times of low-flow and are resuspended and carried downstream during high discharges. While this waste does not normally have a high oxygen demand, it creates problems in water treatment, impairs the growth of desirable aquatic life, and prevents exploitation of sand and gravel deposits downstream.

The main stem of the Kentucky River is canalized for its entire length by 14 navigation locks and dams. These dams increase the time required for water to travel the length of the river, especially at times of low-flow. If large quantities of oxygen-consuming wastes were

discharged into the canalized section of the river, serious pollution might occur in some reaches. The basin is so sparsely populated that each waste discharge is easily assimilated by the stream in nearly all instances. Evidence of organic pollution does occur in short reaches of the Kentucky River, notably in the Irvine-Ravenna vicinity and in the Frankfort vicinity. Except for these two reaches, the main stem of the Kentucky River is free of any significant amount of organic pollution. When the primary sewage treatment plant now under construction at Frankfort goes into operation, the water quality in this reach will improve.

A study of conditions at Frankfort by the Kentucky Water Pollution Control Commission indicates, however, that even with primary treatment at Frankfort and equivalent treatment at a distillery discharging into the Kentucky River immediately below Frankfort, additional treatment may be required to prevent excessively low dissolved oxygen values below Frankfort. This study indicates that at drought flows of 250 cfs* at Frankfort, dissolved oxygen depletion to about 33 per cent of saturation can be expected. Intermediate treatment at Frankfort or equivalent at the distillery or regulation of production at the distillery as related to pounds of B.O.D. and river flow would raise the dissolved oxygen concentration to about 42 per cent of saturation.

Several of the smaller streams in the lower part of the basin contain municipal and industrial wastes. The Elkhorn Creek system receives waste from Lexington, Georgetown, several distilleries, and other communities.

* The minimum monthly average discharge which has a probable frequency of occurrence of once in ten years.

These wastes have all been treated to some extent, and the pollution loads are assimilated before the main river is reached. Benson Creek and Glenns Creek receive distillery wastes. Other small streams carry a small amount of sewage. The wastes entering the Kentucky River through these streams are easily assimilated in the main stream.

Benefits of Increased Flow

The coal washeries on tributaries of the North Fork would not be affected by increased flow. Their waste problem is primarily disposing of coal fines from the washing process. If flow augmentation were provided in the streams to which these wastes are discharged much of the solid material would be carried farther downstream, merely extending the same problem.

In evaluating the benefits from the dilution of sewage as opposed to treatment, it is assumed that primary treatment is always necessary. Dilution may, however, substitute for intermedia - or complete sewage treatment. Benefits attributable to augmentation flows are the difference between the cost of building and operating a primary sewage treatment plant and the equivalent cost for complete or intermediate sewage treatment.

In the Kentucky River Basin, the seven areas listed in Table II are the only ones which need additional sewage treatment, according to the Kentucky Water Pollution Control Commission. Of these, Beattyville, Jackson, and Irvine-Ravenna need only primary treatment in any case; no benefits can be attributed to low-flow augmentation for these communities. The Neon, Fleming, and McRoberts area is on the headwaters of the North

Fork; it does not appear that a dam could be built to aid this waste disposal problem. Lexington discharges to the headwaters of Town Branch of Elkhorn Creek; a possible damsite for aiding this waste disposal problem is not evident. The other three communities needing additional treatment are located where flow regulation might be possible.

Hazard is located on the North Fork of the Kentucky River. The minimum flow in the North Fork at this point, on a one-month-in-ten-years basis, is about 2 cfs; under these flow conditions complete treatment is needed at Hazard. A continuous minimum flow of 8.2 cfs at Hazard would maintain the same downstream water quality with primary sewage treatment as would be expected with secondary treatment at present minimum flows. This represents a flow augmentation of 6.2 cfs at Hazard.

The benefits which the community would receive from this flow augmentation are estimated from the difference between the annual costs of secondary treatment and of primary treatment. In calculating the annual costs, it is assumed that sewage plant designs would anticipate a population increase of ten per cent, that the cost of each treatment plant would be amortized over a 25-year period at 4.5 per cent, and that the life span of the dam would be 50 years. The estimated costs of the treatment plants are derived from the average costs of similar plants built in Kentucky since 1948, with the costs adjusted to 1956 price levels, and from previous Public Health Service studies on the differences in construction and operating costs between primary and secondary treatment. Thus, Hazard would benefit by $7050 a year.

Manchester is located on Goose Creek, a tributary of the South Fork. Data on minimum flows to be expected at Manchester are not available. At Booneville, near the mouth of the South Fork, twenty-one years of record show that ten-day flows of 0 cfs and monthly flows of 0.1 cfs have occurred. Since the drainage area at Booneville is about ten times larger than that at Manchester, it seems reasonable to assume that, at times of minimum flow, virtually all the flow in Goose Creek is Manchester's sewage. Using this assumption, a theoretical calculation* of oxygen sag in the stream indicates that a continuous minimum flow of 2 cfs at Manchester would be required to maintain a minimum D.O. of 4 ppm downstream.

Annual benefits to Manchester were calculated as for Hazard; they would be $2240 a year for a continuous minimum flow of 2 cfs in Goose Creek at Manchester.

In this case an additional benefit would result from the improved water quality exceeding that produced by the secondary treatment recommended by the Kentucky Water Pollution Control Commission. This benefit can be estimated from the difference between the annual cost of secondary treatment and the cost of the even more complex treatment now necessary to maintain a minimum D.O. of 4 ppm in Goose Creek below Manchester. The additional annual benefit obtained is $1700 per year; this must be regarded as nonattributable to Manchester, since the degree of treatment required is greater than that recommended by the Kentucky Water Pollution Control Commission.

* The constants used in this calculation were D_a = 1 ppm, k_1 = 0.16, k_2 = 0.52, untreated B.O.D. load = 319 lbs/day.

At Frankfort a higher degree of treatment of a local distillery's waste or regulation of production as related to pounds of B.O.D. and river flow may be required to maintain a satisfactory minimum dissolved oxygen concentration in the Kentucky River. If a continuous minimum flow of 400 cfs were provided at Frankfort, the additional flow could substitute for a higher degree of industrial-waste treatment at that point. The benefit in this case is based on the cost of the higher degree of treatment, and was estimated to be $7900 annually.

As the drought flow at Frankfort is 250 cfs, an augmentation of 150 cfs would be required to maintain a minimum of 400 cfs. The Buckhorn Reservoir is expected to provide about 50 cfs of this augmentation. The benefit would be derived partly from Buckhorn releases and partly from the other reservoir releases required to make up the necessary discharge.

WATER SUPPLY

Municipal

Of the 54 municipal water supplies in the basin, 27 are wholly or in part dependent on surface water supplies. A summary of these supplies is presented in Table VII. These 27 surface water supplies serve 187,000 people, who consume 18.2 mgd. The majority of surface and ground water supplies of the Kentucky River Basin appear to be adequate in quality and quantity for present and anticipated future needs.

Manchester, supplied mainly by Goose Creek, has in the past experienced some difficulty with acid water and suspended coal fines; the coal came from washeries above the city water intake and would not have been dispelled by low-flow augmentation. The North Fork of the Kentucky River, the source of the municipal supply of Hazard, has had flows of less than one cfs during the period 1940-1954. The yearly average pumping rate exceeded those low flows. Apparently the municipality resolved the problem by limiting water use during the low flows. Normally, the demand for water is greater during periods of low stream flow. While it is possible for a municipality to exist with a limited water supply for short periods, such a situation usually causes great inconvenience to the public, and involves risk in case of fire. Obviously, there is no supply for either industrial or population expansion.

An assured water supply, such as could be furnished from a multipurpose reservoir, would be of great value to that community. The benefit of an assured water supply from a multipurpose reservoir would be the same as the most economical alternative water supply. Due to uncertainties of

Table VII

Surface Water Supplies

Community	Pop. Served	Consumption gpd	Source
Williamstown	1,863	117,000	Impoundment
Owenton	1,298	82,000	Impoundment
Eminence	2,206	104,000	Impoundment
Frankfort	15,449	2,577,000	Kentucky R.
Lawrenceburg	3,179	274,000	Kentucky R.
Versailles	3,055	190,000	Kentucky R.(1)
Midway	900	38,000	Lee's Br.
Lexington	80,000	8,530,000	Impoundment & Ky. River
Wilmore	2,431	106,000	Kentucky R.(1)
Harrodsburg	5,239	273,000	Kentucky R.(2)
Danville	11,540	989,000	Herrington L.
Lancaster	2,394	75,000	Impoundment(1)
Richmond	10,717	899,000	Impoundment(1)
Berea	3,800	363,000	Impoundment(1)
Irvine	4,238	291,000	Kentucky R.
Winchester	11,157	845,000	Impoundment
Leatherwood	2,150	327,000	Impoundment(1)
Hazard	9,800	882,000	N. Fk. Ky. R.
Jenkins	8,800	809,000	Impoundment(1)
Beattyville	1,042	54,000	N. Fk. Ky. R.
Oneida	461	12,000	Goose Ck.
Manchester	1,745	121,000	Goose Ck.
Jackson	1,990	100,000	N. Fk. Ky. R.
	185,454	18,058,000	

(1) Additional supplies from ground water.

(2) Supplementary intake.

wells in that area for large supplies, the use of ground water was not considered.

An impoundment structure was considered the most practical alternative method of developing an assured water supply for Hazard. Costs for the structure were developed by using cost data from the water supply dam constructed for the City of Corbin, Kentucky. The costs were adjusted by the ENR index.

The capital cost of the impoundment structure was estimated to be $843,000. Assigning a life of fifty years and an interest rate of 4½ per cent to the project, the annual charges for an independent water supply development would be $42,600. Therefore, the benefits assignable to a multipurpose reservoir on the North Fork of the Kentucky River upstream from Hazard would be $42,600 plus maintenance arbitrarily taken as $3,400, for a total of $46,000 annually.

The records of flow for 47 years in the Kentucky River near Winchester, Kentucky indicate that daily flows frequently would not be adequate to properly supply Winchester, Lexington, and Richmond. As in the case of Hazard, an assured water supply for these cities would have a tangible value to the cities concerned. The benefit of an assured water supply from a multipurpose reservoir would be based upon the most economical alternative water supply. Ground water supplies were not considered for the same reason as given for Hazard.

The Lexington Water Company, which furnishes water to 80,000 people, formerly obtained its water supply from the South Fork of Elkhorn Creek.

Recently, an intake has been placed in the Kentucky River. The latest information indicated that the entire raw water supply was taken from the Kentucky River. As the Water Company has an existing impoundment which it could draw upon during low-flows in the Kentucky River, it is not believed that the full value of the alternative structure could be assigned a multipurpose reservoir as a benefit. Arbitrarily, a factor of fifty per cent was selected. Again using cost data developed from Corbin, Ky., and assigning a fifty year life and a 4½ per cent interest rate to the project, and applying the fifty per cent factor, the annual charge including maintenance and operation would be $175,000. The annual benefit assignable to a multipurpose reservoir furnishing the required water supply would be $175,000.

The current source of water supply of Winchester, Ky. is reported to be from two impounding reservoirs on Lower Howards Creek. Winchester furnishes water supply to 11,157 people. Richmond currently has an impounding reservoir on a tributary to Otter Creek. Richmond supplies water to 10,717 people. Both municipalities are believed interested in taking a water supply from the Kentucky River. If this is done, an assured water supply would have a tangible value assignable as a benefit of a multipurpose reservoir.

The cost computations were made in the same manner as for Lexington as both communities would have emergency storage in existing impoundments. The benefits assignable to a multipurpose reservoir for furnishing an assured water supply to Richmond and to Winchester including maintenance and operation would be $50,000 annually.

The estimated minimum continuous discharge necessary from impoundment reservoirs for water supplies for Lexington, Richmond, and Winchester is 100 cfs under present conditions. Should large water using industries move into the area, the quantity of water necessary would have to be revised.

Industrial

Industrial water is taken from both surface and ground waters. The 16 coal washeries and the 10 distilleries now operating in the basin are the primary industrial water users. Railroads also use large quantities of water at numerous watering points. The water supplies required by these and the few other industries in the basin are adequate for the present in both quality and quantity, with reserve supplies available in most cases. Therefore, no tangible benefits to present industrial water supplies, other than that to a distillery at Frankfort, can be attributed to flow augmentation in the Kentucky River System.

Benefits of Increased Flow

The quantity of water in the Kentucky River and tributaries, especially in the upper Basin, is limited by poor low-flow characteristics of the stream. With a watershed of its area and with an average annual rainfall of 45 to 48 inches, there is a potentially abundant water supply. If the river were better regulated, by a system of reservoirs to reduce the crest of the peak flows and to store water for release during low-flow periods, the Kentucky River Basin would have water resources to support numerous industries.

It has previously been reported by others that the area has basic

raw materials which can support industries of the type which are seeking water for cooling and processing purposes. In minerals, there are huge deposits of coal, commercial deposits of high calcium limestone, oil and gas, clays, rock asphalt, sand and gravel, phosphate rock, lead and zinc ore, barite, calcite and fluorspar. In or nearby the Basin, there are indications that salt brines may be available in quantities and chemical properties adequate for use as a chemical raw material. The forest resources of the area are extensive and commercial lumber operations are sizeable. The forests have been studied by the pulp and paper industry. It is believed that additional water would encourage industrial development.

The largest single benefit attributable to reservoir operation should be based upon the development of an adequate industrial water supply. This potential tangible value should be very large. The lack of industrial water supplies in sufficient quantity is a significant factor in holding back the industrial development of the Kentucky River Basin.

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